

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 278

GUIDELINES ON THE SUBJECTIVE 10-DAY OCEAN FEATURE
PREDICTION EXPERIMENT

STEPHEN J. AUER
DEVELOPMENT DIVISION

JULY 1983

THIS IS AN UNREVIEWED MANUSCRIPT, PRIMARILY INTENDED
FOR INFORMAL EXCHANGE OF INFORMATION AMONG NMC STAFF
MEMBERS.

278

I. INTRODUCTION

The Marine Products Branch of NMC and the Satellite Analysis Branch of NESDIS conducted an experiment during the first half of 1982 to determine the feasibility of producing a subjective Gulf Stream System feature prediction. This paper is a summary of the 10-day ocean feature prediction experiment.

Since May 1980, NWS and NESS have jointly produced the daily Oceanographic Analysis. This operational product provides the synoptic locations of the oceanic thermal features in the NW Atlantic and Gulf of Mexico, such as, the Gulf Stream System, eddies, and shelf/slope front. The products' data source consists of infrared satellite imagery and in-situ oceanographic data. User reaction to the Oceanographic Analysis has been positive. However, some marine users of the daily analysis have expressed a desire to receive a Gulf Stream forecast product also. With the increased operating costs of ships' a good prediction product would aid in cost effective planning of their operations.

The principal analysts of the Oceanographic Analysis (as of 6/82), myself and Jennifer Wartha Clark (NESDIS), felt that a subjective prediction scheme was plausible because we had acquired a good idea of the general movements of these features in performing the daily synoptic analysis and in reviewing the monthly events for the Oceanographic Monthly Summary. We also felt that a forecasting product would balance the ocean feature information available to the public, as the public could then access the past, present, and predicted future movements of Gulf Stream features in planning their marine operations.

In setting up the prediction experiment, we first reviewed the scientific literature on Gulf Stream feature movements. We also conducted

an independent survey of the feature movements from the previous year's Oceanographic Analysis. From this background, I drew up prediction guidelines for the experiment. The experimental product was a 10-day prediction which was updated each Friday. The general technique for performing the prediction was to use the most recent Oceanographic Analysis as the initial conditions and to predict the translatory movements of the features according to the recently observed individual case feature rates or to the average historically observed feature rates. The features predicted were the Loop Current, the Gulf Stream North and South Walls out to 55°W, anticyclonic eddies, and cyclonic eddies. The eddies on the product were named the same as in the Oceanographic Monthly Summary. The experimental prediction product effort ran from January 25 - June 4, 1982. This paper will describe the prediction guidelines and compare an experimental 10-day prediction with the observations.

II. PREDICTION GUIDELINES

These guidelines are arbitrarily broken down into Gulf Stream System regions and eddies, namely, the Loop Current, Gulf Stream from 83°-75°W, Gulf Stream from 75°-55°W, Gulf of Mexico warm eddies, Gulf Stream warm eddies, and Gulf Stream cold eddies. The guideline for each component is given in two parts. Part 1 gives the average expected movement of the feature as determined from the literature or our independent survey. Part 2 gives the prediction guideline. The 10-day prediction is updated every Friday. The general procedure is to use the Thursday (previous day) and Friday (same day) Oceanographic Analysis as the "first guess". The Thursday analysis chart contains the Loop Current and Gulf Stream out to 75°W. The Friday analysis chart contains the Gulf Stream from 75°-44°W. For each feature component "look back" at the previous movements,

from 1 week to 2 months, and determine a mean translation rate. Then, decide whether to use the mean rate, the latest translation rate, or the general average guideline rate (given in Part 1), or some combination of the above. Using the decided upon translation rate, make the 10-day prediction. Actually, for features whose last date of observation is not today (Friday) the prediction period is correspondingly longer. For example, if a "first guess" eddy position was actually observed 4 days ago, the decided upon translation rate would be applied for 14 days to make the 10-day prediction.

A. Loop Current

1. Average movement: The Loop Current slowly intrudes westward and northward into the Gulf of Mexico and eventually pinches off shedding a large anticyclonic eddy. The Loop Current enters thru the Yucatan Strait and exits thru the Straits of Florida. Its maximum observed westward intrusion is 90°W and its maximum observed northward intrusion is 28.5°N (Auer 1983). The independent study showed that the Loop's northward intrusion rate is slow, about 1 km per day.

The Loop appears to propagate anticyclonic eddies in two ways (Fig. 1). In the classical eddy formation, the Loop reaches a maximum northward intrusion into the Gulf at about 28°N and pinches off below 25°N forming a large warm eddy and leaving a greatly reduced Loop (Leipper 1970) and (Maul 1977). There is some controversy as to whether this eddy shedding is an annual event or not (Molinari 1978). Our independent study indicates that it may be a non-annual cycle, with eddy shedding perhaps occurring at an average of once each eight months. In the second eddy formation case, a small protrusion on the northeastern side of the greater Loop breaks off above 25°N forming a small warm eddy and leaving the bulk of the Loop

Current intact. Our independent study indicates that these events may also occur about once every 8 months. This eddy formation type has not been discussed in the literature, to my knowledge.

2. Prediction Guidelines: From past experience evaluate the stability of Loop Current for the possible pinching off of a warm eddy. If Loop is not expected to pinch off, compare northern edge of Loop Current on "first guess" with edges for past month, or so, to find mean northward intrusion rate. Use this mean rate or the general average rate of 1 km/day. Apply decided upon rate for the period from date of last observation to 10-day prediction date. In drawing Loop Current edge, disregard small filaments isolated from main flow and draw a smoothed edge. (NOTE: Loop Current is usually not definable by satellite infrared imagery from July-October due to the intense solar heating which relaxes the surface temperature gradients. Thus a 10-day prediction will not be feasible during this period.)

B. Gulf Stream 83°-75°W

1. Average movement: Gulf Stream shows little variability from 83°-79°W as current hugs continental shelf near 200-m isobath as it flows through Florida Straits and off the east coast of Florida. Gulf Stream from 79°-75°W shows more variability as small amplitude waves propagate downstream from "Charleston Bump" topographic feature (32°N 78°W) to Cape Hatteras in 4-11 days (Legeckis 1979) and (Brooks 1978).

2. Prediction Guideline: Don't predict any new position for Gulf Stream in this area. Use latest Stream position and smooth out protrusions from main flow. Small amplitude waves in Stream area 79°-75°W transverse downstream through area within 10-day prediction period, so we can't anticipate new wave pattern as we don't know what drives it. Therefore

this region of Gulf Stream System will not be a true prediction. Perhaps future prediction efforts in area should use the mean climatological position of Stream, rather than the last observed position.

C. Gulf Stream 75°-55°W

1. Average movement: Gulf Stream exhibits large variability in this region, especially east of 70°W where large amplitude meanders are found. Meanders in the Gulf Stream translate an average 5-10 km/day downstream (Hansen 1970). Smaller amplitude meanders translate faster than larger ones (Orlanski 1973). Meanders can grow in amplitude and periodically can break off from the Stream forming warm (anticyclonic) or cold (cyclonic) eddies (Fuglister 1972). All warm eddies are eventually absorbed back into the Stream. Our independent study illustrates that the warm eddies do not dissipate along the shelf/slope front or within the slope water region, but they are absorbed by the Gulf Stream along its North Wall edge or by another warm eddy (a rare event). Cold eddies are also absorbed back into the Gulf Stream. The absorption of a cold or warm eddy into the Stream may form an open meander in the Stream; or if the eddy is absorbed by an existing Stream meander it can increase the amplitude of that meander (Richardson 1980).

2. Prediction Guideline: Evaluate stability of Gulf Stream meanders for possible eddy formation within 10-day prediction period. Also, evaluate if an existing eddy will interact with the Stream and if so, what the consequences will be. Review the recent translation and movements of individual Stream meanders as to their growth rate and translation rate downstream. Decide whether to use observed recent rates of meander translation or employ an average downstream translation rate of 7.5

km/day. Unfortunately, we were not able to discover a general meander growth rate guideline, so meander amplitude growth is left up to the analyst's discretion.

D. Loop Current Warm Eddies

1. Average movement: Loop Current eddies translate 2 km/day into the western Gulf of Mexico (Elliot 1979). Independent study agrees with this estimate. Eddies apparently dissipate along western Gulf of Mexico shelf. Eddies generally become difficult to track as they translate into the western basin of the Gulf due to a weakening of their surface signal. Also, summertime seasonal heating prevents monitoring of these features by satellite imagery from about July-October.

2. Prediction Guidelines: Compare recent translation rates of warm eddy. If previous translations are unavailable or suspect use the general 2 km/day westward movement for prediction. The small eddies formed by Loop protrusions are occasionally reabsorbed by Loop Current; evaluate if this is possible, if so, this event may increase the amplitude of Loop.

E. Gulf Stream Warm Eddy

1. Average movement: Warm eddies normally translate in a west to southwest direction at about 3 km/day (Richardson 1980), but range 0-15 km/day. Higher speeds usually only occur in short spurts (independent study). West of 65°W an eddy may follow the 200-m isobath nearly to Cape Hatteras before being absorbed by the Stream.

2. Prediction guideline: Determine recent eddy translation rates. The rate for the previous 2 weeks seems to be a good guide. If recent rate is unavailable or suspect use general 3 km/day in west to southwest direction. If recent translation speed is much greater than the norm, it is probably wise to use a reduced value for the prediction. Evaluate for the

possibility of Gulf Stream (or another warm eddy) absorbing the warm eddy. Generally, one can decide this by plotting the predicted movements of all the features on the base chart and see if any are predicted to collide. Eddy sizes are not altered for the prediction.

F. Gulf Stream Cold Eddy

1. Average movement: Independent study and literature show an average translation of 2 km/day in southwest to south direction (Richardson 1976).

2. Prediction guideline: As for warm eddies, determine recent cold eddy translation rate. If this rate is unavailable or suspect use 2 km/day rate. Cold eddies are hard to track because, being cooler and denser than the surrounding Sargasso water, they tend to sink making surface identification difficult. Thus, cold eddy sightings are sporadic. The best conditions for a sighting are just after formation by the Stream or when they later drift near the Stream and entrain the warmer Stream water cyclonically around them in a characteristic hook. Care must be taken in determining cold eddy movements when long gaps occur as to whether an eddy is the same eddy seen previously or is it a new one. This feature prediction will probably be the weakest part of the prediction effort.

III. 10-DAY PREDICTION

Figures 2 and 3 are examples of a 10-day prediction made during the project. Figure 2 shows the prediction for the Loop Current and the Gulf Stream up to Cape Hatteras. Figure 3 shows the Gulf Stream from Cape Hatteras to 55°W. The predicted feature boundary positions are demarked by lines and dots in order to show the relative ages of the "first guesses" (last observed feature position). Solid lines represent feature positions seen within two days prior to the prediction. Dashed lines are for feature positions seen two to seven days before the prediction. Dotted lines are for positions seen more than seven days before the prediction. Shown on the top or bottom margin of each chart are the pertinent data for each feature in terms of name, last observed date, recent translation rates and directions, and the predicted translation rate selected by the analyst.

IV. COMPARISON

How good are the 10-day experimental predictions. One would at least expect that the subjective predictions would be a better prediction than the initial conditions. In most cases the prediction was, but in a few cases it was not. To illustrate the value of the 10-day prediction, figures 4 and 5 compare the March 29, 1982, observations with the 10-day prediction and the March 19, 1982, initial conditions.

Looking at Figure 4, the predicted position of the Gulf Stream ridge near 69°W coincides closely with the observed position. The predicted eastward translation of the downstream trough near 67°W is also good, but it does not capture the deepening of it. The prediction poorly handles the ridge near 66°W, which remained nearly stationary and increased in amplitude. The initial conditions are a better prediction of this ridge. The predicted pinch-off of and new eddy formation from the Stream meander

near 64°W does not occur. However, the combined predicted eddy and remaining meander positions do approximate the observed meander position. The predicted eastward translation of the trough to near 62°W is good, although the orientation of the trough axis is not quite right. The initial conditions handle the meander amplitude, but not the trough. Neither predictor (10-day prediction or initial conditions) indicates the new short wave development near 58°30W. The prediction of the meander translation near 56°W is good, but a bit too fast. The prediction does not show the increase in meander amplitude. The prediction does a good job of indicating the translation (speed and direction) of warm eddies 12, 17, and 16. However, eddy 13, which remained nearly stationary, and eddy 14, which was pushed northward by the growing meander south of it, were not well predicted.

Looking at figure 5, the predicted northward increase in Loop Current amplitude exactly matches the observed. The prediction does a good job in showing the southwest translation of warm eddy e. The predicted southwest translation of eddy d was wrong, as eddy d apparently moved slightly east. Thus, the initial condition position of eddy d was a better predictor. The prediction does a good job of forecasting the movements of cold eddies X and Z, but "bombs out" on forecasting the movement of eddy A. Other cold eddy comparisons can't be made due to a lack of observations.

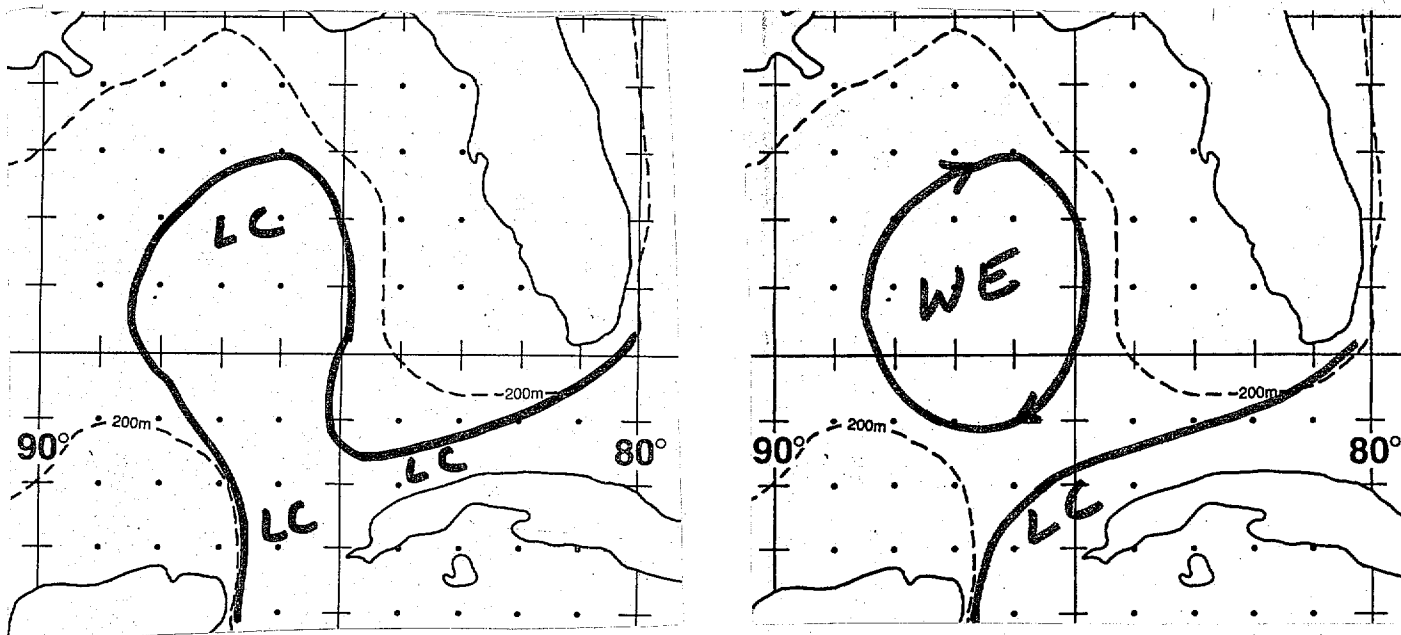
In summary, as shown in the above comparison and from reviewing the results of the other 10-day predictions which were not shown, the experimental subjective prediction is a good guide for projecting warm eddy movements, Gulf Stream meander translations, and Loop Current amplitude growth. It may also be a useful indicator of cold eddy movements, but the sparsity of cold eddy observations prevents a clearer interpretation of this. Also, the prediction can project the formation and absorption

of eddies by the Gulf Stream and Loop Current. Although the predicted eddy formation for March 29 was wrong in the above comparison, in two other cases during the experiment, the predicted eddy formation events were verified as correct. On the negative side, the prediction poorly handles Gulf Stream meander growth and any anomalous movements of Gulf Stream meanders and eddies, such as, meanders that remain stationary or retrogress and eddies which translate north or east, instead of, south or west.

REFERENCES:

- Auer, Stephen J., 1982: Gulf Stream System Landward Surface Edge Statistics (In preparation as NOAA Technical Memo).
- Brooks and Bane, 1978: Gulf Stream Deflection by a Bottom Feature Off Charleston, South Carolina, Science, 201, 1225-6.
- Elliot, 1979: Anticyclonic Rings and the Energetics of the Circulation of the Gulf of Mexico. Ph. D. thesis, Dept. of Ocean., Texas A & M, 188 pp.
- Fuglister, 1972: Cyclonic Rings Formed by the Gulf Stream. 1965-66, in Studies in Physical Oceanography. A Tribute to George Wust on his 80th Birthday. Gordon and Breach. 1, 137.
- Hanson, 1980: Gulf Stream Meanders Between Cape Hatteras and the Grand Banks. Deep-Sea Research, 17, 495-511.
- Legeckis, 1979: Satellite Observations of the Influence of Bottom Topography on the Seaward Deflection of the Gulf Stream off Charleston, South Carolina. Journal of Physical Oceanography, 9, 483-497.
- Leipper, 1970: A Sequence of Current Patterns in the Gulf of Mexico, Journal of Geophys. Research, 75, 637-57.
- Maul, 1977: The Annual Cycle of the Loop Current. Part I. Observations During a One-Year Time Series, Journal of Marine Research, 35, 29-47.
- Molinari, 1978: An Overview of the Circulation in the Gulf of Mexico, Summary Report: Working Conference on the Circulation in the Gulf of Mexico, Dept. of Oceanography, Florida State University, 29-30.
- Orlanski and Cox, 1973: Baroclinic Instability in Ocean Currents, Geophys. Fluid Dyn., 4, 297-332.
- Richardson, Phillip 1976: Gulf Stream Rings, Oceanus, 19:3:65-68.
- _____, 1980: Gulf Stream Trajectories, Journal of Physical Oceanography, 10, 90-104.

Case 1. Classical Loop Current Eddy formation.



Case 2. Small Loop Current Eddy formation.

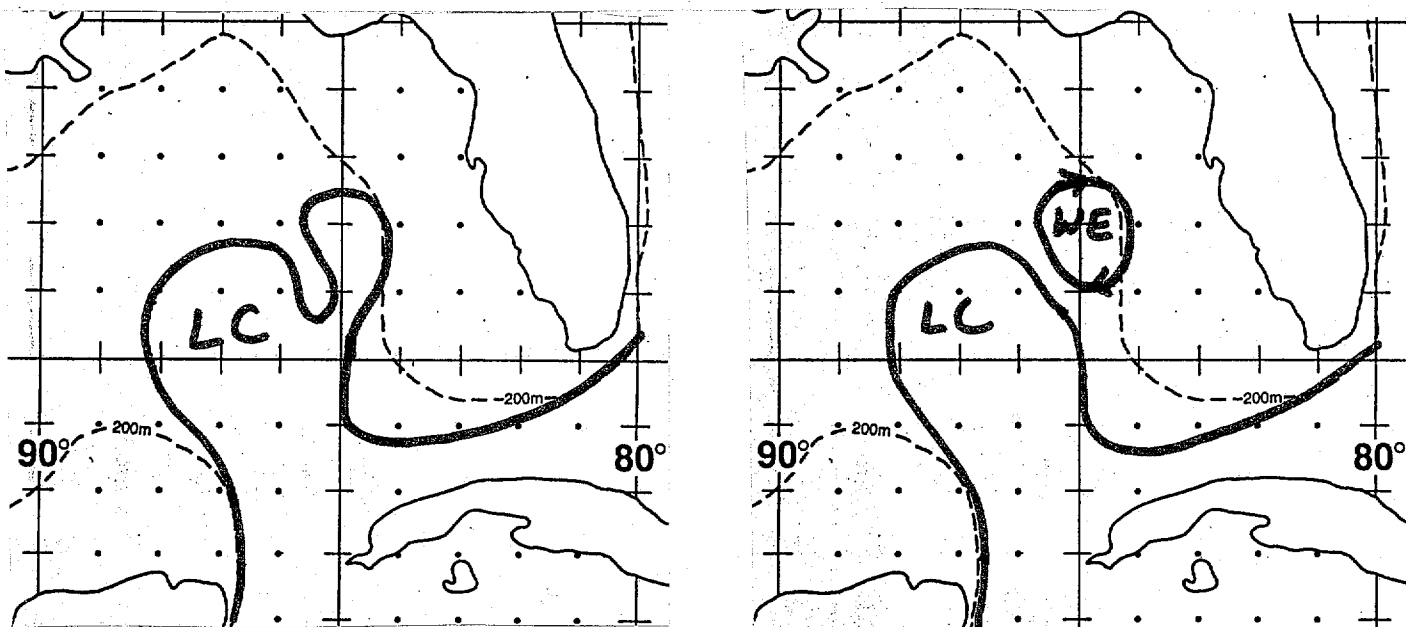


Figure 1. Loop Current Warm Eddy propagation methods.

GS Meanders - ~~predicted~~ 7.5 km/d downstream

WE 18 - predicted new WE

WE 12 - 3/12-19 moved 4 km/d SW, predict same

WE 17 - 3/12-19 moved 5 km/d WSW, predict 4 km/d WSW

WE 16 - 3/12-19 moved 7 km/d SW, predict 5 km/d SW

WE 13 - 3/12-19 moved 13 km/d WNW, predict 6 km/d WSW

WE 14 - 3/12-19 moved 5 km/d SE, predict 3 km/d W.

CE R - 2/27-3/19 moved 4 km/d ESE, predict 2 km/d SW

CE C - newly observed 3/12, predict 3 km SW.

CE Z - 2/12-19 2 km/d E, predict 2 km/d SW

OCEANOGRAPHIC ANALYSIS
10 DAY PREDICTION
PREDICTION DATE: 3/29/82

PREPARED BY: Steve Auer

PREPARATION DATE: 3/19/82

NATIONAL WEATHER SERVICE

NATIONAL EARTH SATELLITE SERVICE

SYMBOL LEGEND

GS	GULF STREAM
WE	WARM EDDY
CE	COLD EDDY
—	FRONTAL LOCATION
---	ESTIMATED FRONTAL LOCATION
→	DIRECTION OF FLOW, NOT AXIS

Key for Submarine Canyons:

C	- Corsair Canyon
L	- Lydonia Canyon
Hy	- Hydrographer Canyon
A	- Atlantis Canyon
Bl	- Block Canyon
H	- Hudson Canyon
W	- Wilmington Canyon
Ba	- Baltimore Canyon
Wa	- Washington Canyon

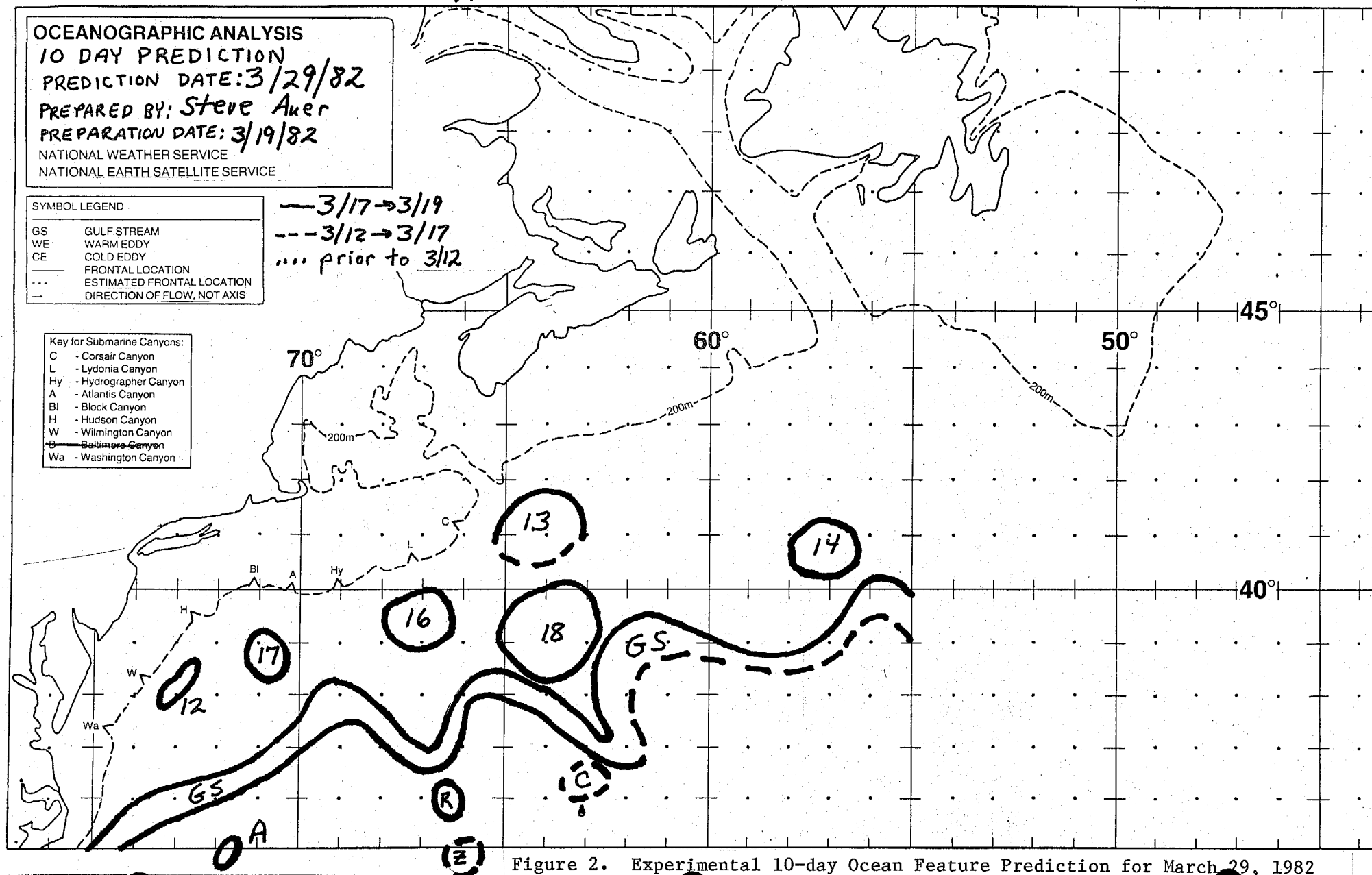


Figure 2. Experimental 10-day Ocean Feature Prediction for March 29, 1982
(val. March 19, 1982).

Figure 3. Experimental 10-day Ocean Feature Prediction for March 29, 1982
(valid March 19, 1982).

OCEANOGRAPHIC ANALYSIS

10 DAY PREDICTION

PREDICTION DATE: 3/29/82

PREPARED BY: Steve Auer

PREPARATION DATE: 3/29/82

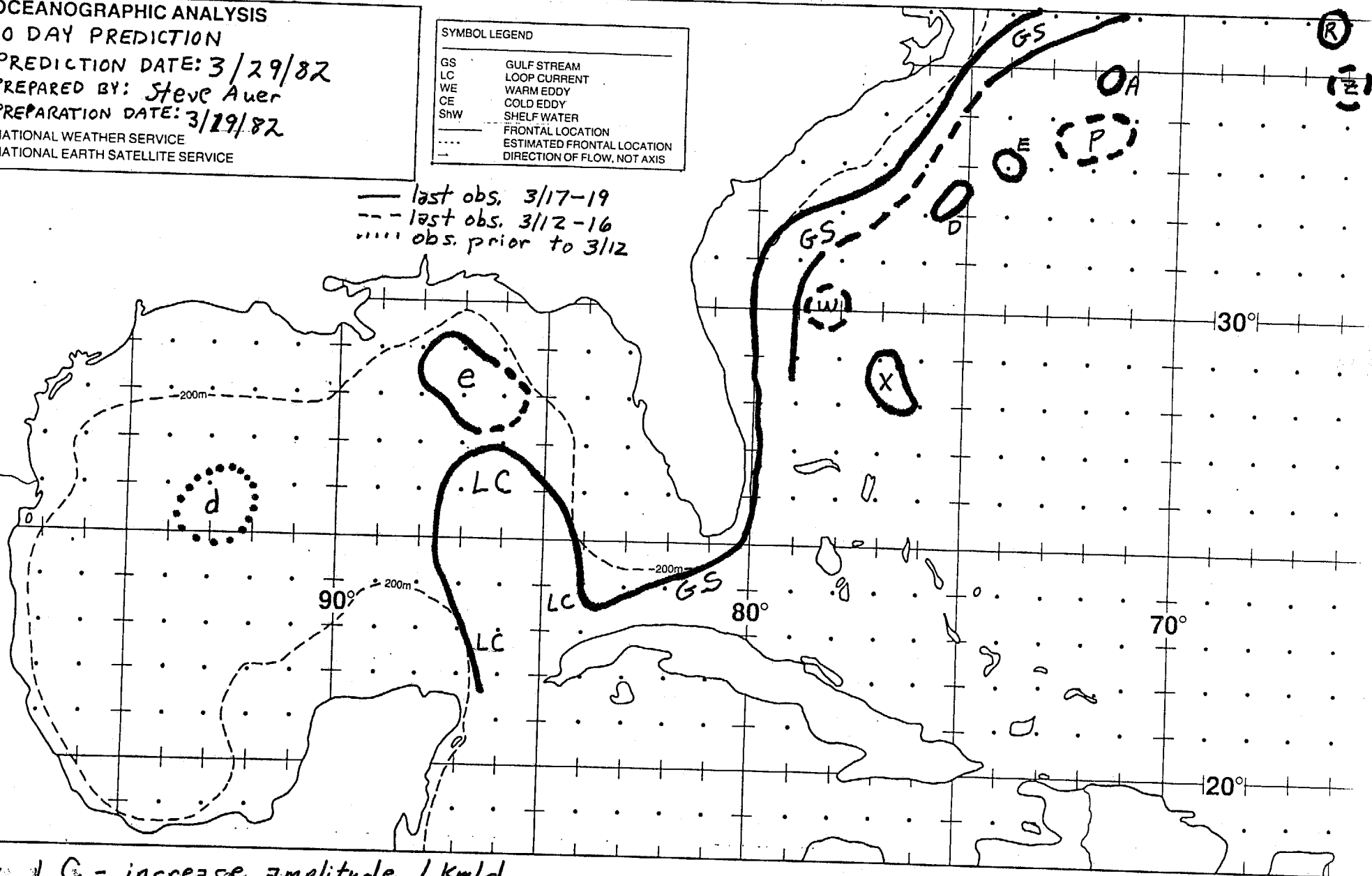
NATIONAL WEATHER SERVICE

NATIONAL EARTH SATELLITE SERVICE

SYMBOL LEGEND

GS	GULF STREAM
LC	LOOP CURRENT
WE	WARM EDDY
CE	COLD EDDY
ShW	SHELF WATER
---	FRONTAL LOCATION
----	ESTIMATED FRONTAL LOCATION
→	DIRECTION OF FLOW, NOT AXIS

— last obs. 3/17-19
 --- last obs. 3/12-16
 obs. prior to 3/12



LC - increase amplitude 1 km/d

WE d - 1/26-2/23 2 km/d NW, predict 2 km/d WSW

WE e - moved 2.5 km/d SW 2/26-3/18, predict 3 km/d SW

CE A - 3/5-3/16 moved 7 km/d SW, predict 5 km/d SW

CE P - previous movements erratic, predict 2 km/d

CE E } newly seen, predict 2 km/d SW
 CE D }

CE W - 2/18-3/16 moved 2 km/d S, predict same

CE X - 3/2-18 moved 5 km/d WSW, predict 5 km/d SW

Figure 4. Comparison of March 29, 1982, observed feature positions (black) with 10-day predicted positions (red) and initial conditions from March 19, 1982, (green).

**OCEANOGRAPHIC ANALYSIS
10 DAY PREDICTION
PREDICTION DATE:**

PREPARED BY:
PREPARATION DATE:

NATIONAL WEATHER SERVICE
NATIONAL EARTH SATELLITE SERVICE

SYMBOL LEGEND

GS GULF STREAM
WE WARM EDDY
CE COLD EDDY
— FRONTAL LOCATION
--- ESTIMATED FRONTAL LOCATION
• DIRECTION OF FLOW, NOT AXIS

Key for Submarine Canyons:

C - Corsair Canyon
L - Lydonia Canyon
Hy - Hydrographer Canyon
A - Atlantis Canyon
Bl - Block Canyon
H - Hudson Canyon
W - Wilmington Canyon
Ba - Baltimore Canyon
Wa - Washington Canyon

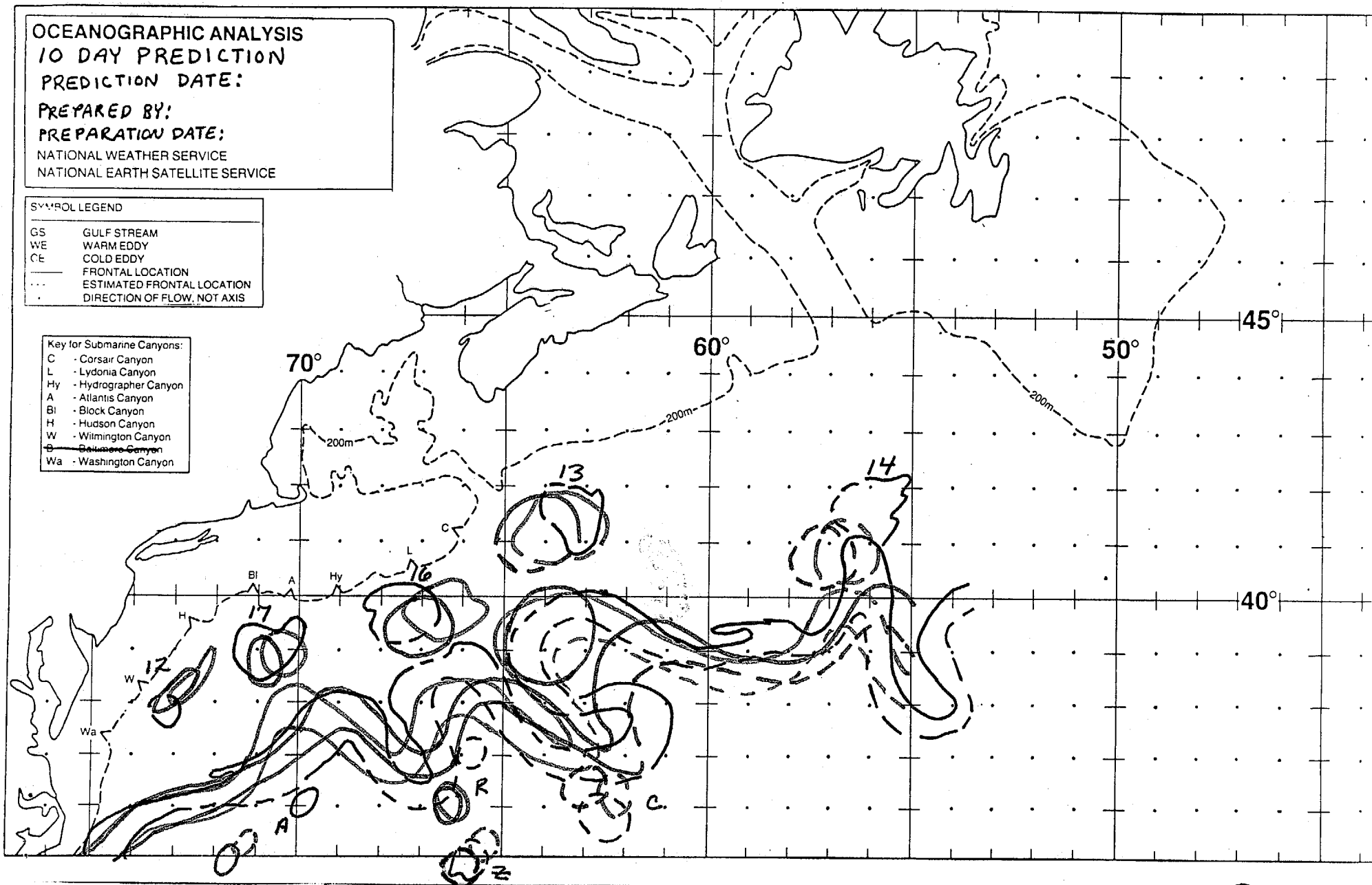


Figure 5. Comparison of March 29, 1982, observed feature positions (black) with 10-day predicted positions (red) and initial conditions from March 29, 1982, (green).

OCEANOGRAPHIC ANALYSIS

10 DAY PREDICTION

PREDICTION DATE:

PREPARED BY:

PREPARATION DATE:

NATIONAL WEATHER SERVICE

NATIONAL EARTH SATELLITE SERVICE

SYMBOL LEGEND

GS	GULF STREAM
LC	LOOP CURRENT
WE	WARM EDDY
CE	COLD EDDY
ShW	SHELF WATER
---	FRONTAL LOCATION
---	ESTIMATED FRONTAL LOCATION
→	DIRECTION OF FLOW, NOT AXIS

